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INFORMATION CIRCULAR

SAND AND GRAVEL EXCAVATION;

PART 6: MINING METHODS

BY

J. R. THOENEN

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INFORMATION CIRCULAR

DEPARTMENT OF THE INTERIOR - BUREAU OF MINES

SAND AND GRAVEL EXCAVATION[1] - PART VI: MINING METHODS

By J. R. Thoenen[2]

INTRODUCTION

This circular is part 6 of the third paper (entitled "Excavation") of a series summarizing the technical problems involved in the production and preparation of sand and gravel. Part 1 discussed the use of power shovels, draglines, and excavator cranes; part 2, power scrapers, slackline cableway excavators, and hydraulic monitors; part 3, hydraulic, clamshell, ladder, and dipper dredges; part 4, haulage equipment, particularly industrial cars with locomotive or hoist as the motive power; part 5, conveyor belt, motor truck, pump and pipe line, towboat and barges, and aerial-tram haulage. This circular discusses the application of these various types of equipment to the different types of sand and gravel deposits and contains a reference bibliography. It completes the discussion of excavating problems.

SELECTION OF A MINING METHOD

Two major factors govern the selection of a method to be used in mining a sand and gravel deposit - type of deposit and type of equipment used. The character of the deposit may limit the choice of equipment to a certain type of excavator and an equally restricted choice of haulage equipment. For example, a deposit covering a lake bed may limit excavation to a hydraulic dredge served by floating barges. Ordinarily, however, any deposit may be worked by different methods involving various types of excavating and haulage units. The proper application of these units to the deposit involves a careful technical and economic study of all local conditions and the experience and preference of the operator. Two operators who have had experience with different types of equipment may operate the same type of deposit successfully by entirely different mining methods. Therefore no exact rule can be laid down definitely linking one type of deposit with any particular method. In a general discussion such as this, without knowledge of limiting local factors, the best plan is to show what methods are applicable to the several types of deposits and point out their advantages and disadvantages, leaving the final selection to the operator.

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2/ Senior mining engineer, U. S. Bureau of Mines.

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TYPES OF DEPOSITS

The author has classified (5)[3/] sand and gravel deposits by types as bank, pit, and marine, defined as follows:

Bank. - A deposit in which the elevation of the excavation floor is level with or above the surrounding land surface.

Pit. - A deposit lying wholly below the level of the surrounding land surface.

Marine. - A deposit forming the bed, bars, or small islands between the banks of a natural body of water.

Pit deposits are subdivided into dry pits, in which the excavation floor is above the level of permanent ground water, and wet pits, in which the excavation floor is below the water level.

Marine deposits are subdivided into river, lake, and ocean, depending upon the type of the body of water.

CLASSIFICATION OF MINING METHODS

There have been numerous discussions and much controversy over the proper classification of mining methods in the technical press, in publications of engineering societies, and as taught at mining colleges. A study of the literature reveals that both discussion and controversy have centered on underground mining methods and that participants have been content to ignore surface methods or to accept without change some brief classification advanced by others. The study further reveals that such classifications of surface mining as have been offered usually have included only those methods used in metal mining with virtually no reference to methods used in mining nonmetallic minerals.

Before methods applicable to sand and gravel recovery are designated, surface mining methods will be defined and classified.

Since the terms "mining method" and "mining system" are often used synonymously it is first necessary to designate definitely what is meant by each. A study of the dictionary definitions shows "method" to be more or less synonymous with "system" and vice versa, for example:

System: Funk and Wagnall's Standard Dictionary (1926). An orderly combination or arrangement, as of particulars, parts, or elements, into a whole. (Method is given as a synonym but distinction is illustrated by the fact that we may have a "system" of taxation but various "methods" are used to collect the tax.)

3/ Numbers in parentheses refer to bibliography at end of this circular.

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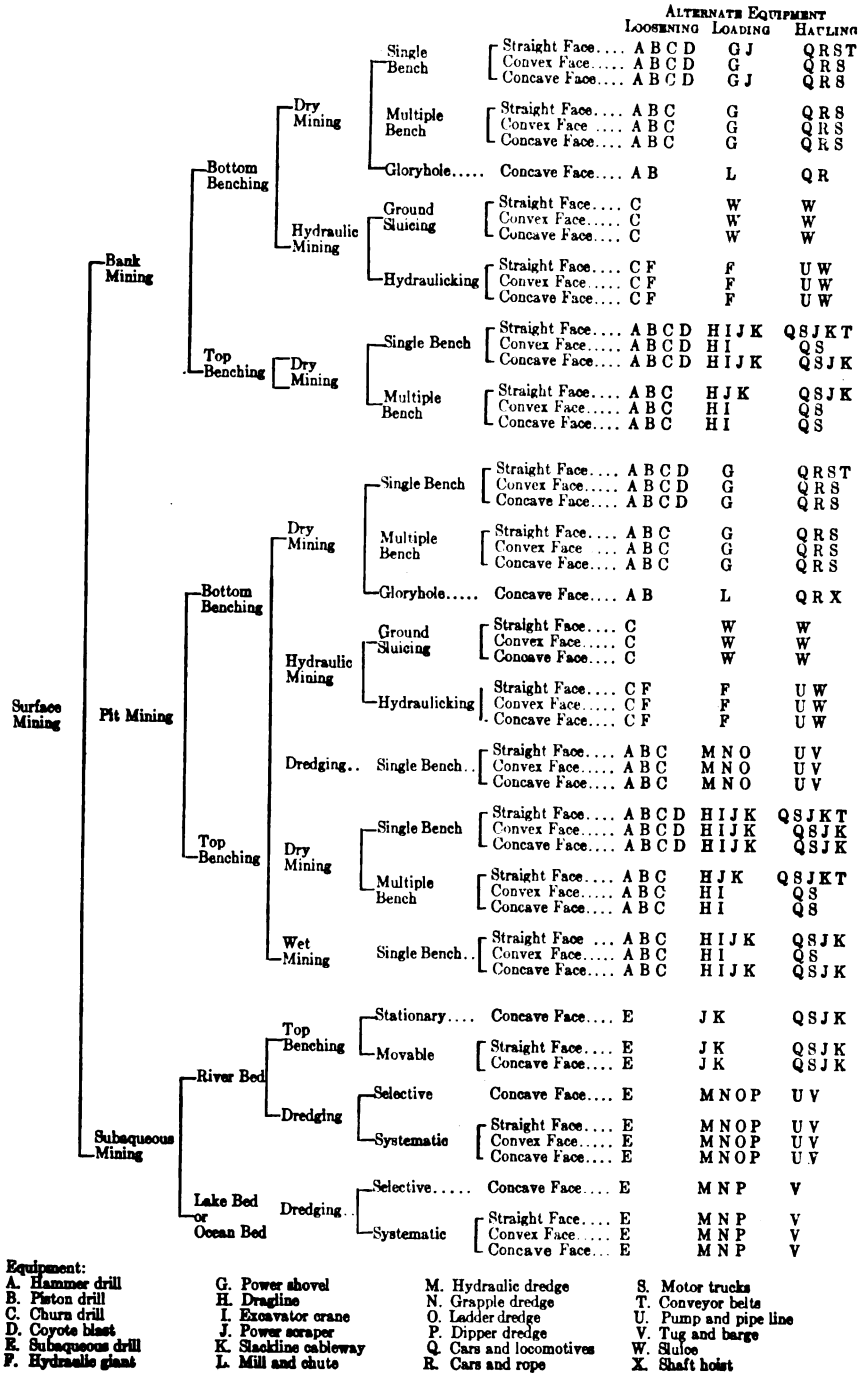
Alternate Equipment
Loosening Loading Hauling
Surface Mining
Bank Mining
Pit Mining
Subaqueous Mining
Bottom Benching
Top Benching
Dry Mining
Hydraulic Mining
Wet Mining
Dredging
River Bed
Lake Bed or Ocean Bed
Single Bench
Multiple Bench
Gloryhole
Ground Sluicing
Hydraulicking
Stationary
Movable
Selective
Systematic
Straight Face A B C D G J Q R S T
Convex Face A B C D G Q R S
Concave Face A B C D G J Q R S
Straight Face A B C G Q R S
Convex Face A B C G Q R S
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Concave Face A B L Q R
Straight Face C W W
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Convex Face A B C G Q R S
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Straight Face E J K Q S J K
Concave Face E J K Q S J K
Concave Face E M N O P U V
Straight Face E M N O P U V
Convex Face E M N O P U V
Concave Face E M N O P U V
Concave Face E M N P V
Straight Face E M N P V
Convex Face E M N P V
Concave Face E M N P V
Equipment:
A. Hammer drill
B. Piston drill
C. Churn drill
D. Coyote blast
E. Subaqueous drill
F. Hydraulic giant
G. Power shovel
H. Dragline
I. Excavator crane
J. Power scraper
K. Slackline cableway
L. Mill and chute
M. Hydraulic dredge
N. Grapple dredge
O. Ladder dredge
P. Dipper dredge
Q. Cars and locomotives
R. Cars and rope
S. Motor trucks
T. Conveyor belts
U. Pump and pipe line
V. Tug and barge
W. Sluice
X. Shaft hoist

Figure 27.—Surface mining classification.

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Webster's New International Dictionary (1935). An aggregation or assemblage of objects united by some form of regular interaction or interdependence; a group of diverse units so combined by nature or art as to form an integral whole and to function, operate, or move, in unison and often in obedience to some form of control; a definite, methodical, or logical order or plan.

Method: Funk and Wagnall's Standard Dictionary (1926). A general or established way or order of doing anything.

Webster's New International Dictionary (1935). An orderly procedure or process; regular way or manner of doing anything. Method is commonly a special or definite way of procedure.

In the absence of further research, "system" is the major term and may include various "methods." Just as a country may have a system of taxation but use various methods of collecting the tax, so each mine may have an orderly "mining system" which may embrace various "mining methods" that are more or less interdependent.

Surface mining is grouped in three major divisions - bank, pit, and subaqueous mining (fig. 27). Bank and pit mining parallel closely the author's classification of types of sand and gravel deposits but are applicable to the mining of any commodity. Subaqueous mining differs from the classification of marine sand and gravel deposits in that it is restricted by definition to the mining of material lying wholly below the surface of a natural body of water. The divergence is made to clarify the method.

All surface mining, regardless of the nature, is carried on by what is generally known as the "bench" method, otherwise called benching or bench working. Bench or benching is defined[4] as "a level layer worked separately in a mine" and bench working as "the system of working one or more seams or beds of mineral by open working or stripping, in stages or steps." Other authors have accepted this designation without further division as applying to the major group of surface methods. There are, however, various ways of mining benches which not only require different types of loading machines but also different methods of intraplant haulage. As it is generally agreed that mining is "the working of any excavation for the development or extraction of the ore, rock, or coal therefrom,"[5] it follows that the term includes not only the primary loosening of the mineral by drilling and blasting but also the process of loading into haulage equipment and removal from the excavation. Therefore any difference in loading or haulage methods constitutes a difference in the mining system. Recognizing the validity of this argument, the author divides both bank and pit mining into two subdivisions based upon the relative position of the loading equipment with respect to the bench being mined. Loading equipment may be either on a level with the foot of the bench or on top of the bench. For example, a power shovel or hydraulic monitor mines a bench from the bottom, whereas a dragline, excavator crane, power scraper, or slackline cableway mines the bench from above or even at times from the top of the overburden.

4/ Fay, A. H., A Glossary of the Mining and Mineral Industry: Bull. 95, Bureau of Mines, 1920, p. 74.

5/ Fay, A. H., Work cited, p. 442.

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The author could find no distinctive names either in general or colloquial use for these two methods of working a bench, and to avoid cumbersome descriptive phraseology he suggests "bottom benching" and "top benching." Bottom benching is used to designate that method by which the bench is removed from below, as with a power shovel. Top benching is used to designate that method by which the bench is removed from above, as with a dragline. The terms may be applied with equal validity, whether the bench is first broken down by drilling and blasting or whether the excavator actually digs from the solid.

Bank and pit mining are then subdivided into bottom and top benching.

As a further subdivision of both the bottom and top-bench methods the benches may be worked dry or with the aid of water. The water may be used directly, as in hydraulic mining, or it may render only indirect or passive assistance as when a bench is only partly submerged.

Bank or pit mining by bottom benching may be divided further into dry mining and hydraulic mining. Bank mining by top benching, however, must be dry mining for obvious physical reasons.

Pit mining by top benching may be either dry or wet mining, although the subdivision wet mining is not identical with hydraulic mining. In this method the water in a wet pit is only an indirect or passive aid in mining an unconsolidated bench.

In pit mining there is an intermediate stage between bottom and top benching in which the bench is mined from an elevation somewhere above the bottom of the bench but below the top. This refers to dredging; the dredge floats on the surface of the water in the pit and mines from below that surface but also excavates the pit bank from above the surface of the water by caving. Strictly speaking, dredging may be a modified form of either bottom or top benching, depending upon the relation of the water surface to the bottom or top of the bench.

Dry-bank mining by bottom benches is subdivided further into single and multiple benching and glory-hole mining. The first two terms are self-explanatory; each may be divided further into benches with straight or curved faces, and if curved, into either convex or concave, depending upon whether the face is worked from the inside or outside of the curve. Glory-hole mining is essentially a multiple concave bottom-bench method, but as this system uses a characteristic method of loading it warrants a special designation.

Hydraulic mining is divided into ground-sluicing, in which no pressure water is used, and hydraulicking, in which the bench is mined by hydraulic giants with water under pressure. Both of these classes may be divided further into benches with straight or curved faces.

In bank mining by top benching single or multiple benches may be worked, and the faces may be straight or curved.

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Pit mining by bottom benching takes parallel subdivisions as in bank mining by bottom benching, except that material mined by the glory-hole method must be hoisted to the surface, whereas in the bank glory hole it can be trammed without elevating.

In pit dredging only single benches are worked, but the faces may be straight or curved.

In dry-pit mining by top benching either single or multiple benches may be worked, although the latter are by no means common. Faces may be straight or curved, convex or concave. In wet-pit mining by top benching only single benches are worked, but they may be straight or curved.

Bank- and pit-mining methods have been discussed together to show their parallelism and emphasize certain differences.

Subaqueous mining generally is top benching by dredges, although in river beds other types of excavators are often used. Subaqueous mining is classed as river, lake, and ocean mining, depending upon the nature of the body of water in which the material lies. Subaqueous river beds may be mined by top benching from stationary or movable shore plants or by floating dredges. The stationary plant uses a single-bench method in which the face is concave or fan-shaped; the movable plant and dredge uses the single-bench method, but the faces may be straight or curved. Dredging may be selective, using concave single benches, or may follow a regular straight- or curved-face method.

Subaqueous mining in lake or ocean beds is single-bench mining but may be selective with concave faces or systematic with convex or concave faces.

Figure 22 shows this classification in chart form.

APPLICATION OF MINING METHODS TO DEPOSITS

A study of the classification chart shows that the mining of sand and gravel deposits of the same type is not restricted to a single mining method nor to a system composed of identical methods. Variation may be small in some instances (two systems may be similar in general but differ in contributing methods) but may result in greater proportionate efficiencies. The problem of selecting the proper method for a given deposit is further complicated by the overburden covering most bank and pit deposits and some marine deposits (82). If the overburden is thin enough to be negligible it is removed in the process of mining the gravel (10, 18, 37, 57); if it is thick enough to cause trouble it is usually removed separately. The stripping method may then parallel the mining method, using the same (22, 23, 54, 62) or different equipment (9, 32, 44, 66), or it may be entirely different from the mining method and require its own set of equipment (16, 25, 28, 62). On the other hand, if different methods are necessary in stripping and

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mining, the same or duplicate equipment may sometimes be used for both (70). However, removal of overburden or stripping is surface mining and is subject to the same classification of mining methods as are sand and gravel. The factors that affect stripping and mining have been discussed in a general way in an earlier paper (5) and will not be repeated here, although they should be kept in mind during the following discussion.

Bank Deposits

In general, bank deposits are mined dry, except where hydraulic mining (35) is employed. Haulage from bank deposits is level or downgrade with one exception, which will be discussed later in this paper. These two distinctive characteristics of bank deposits at once eliminate consideration of dredges and water-borne transportation and permit the design of the haulage equipment for a minimum of power.

Bottom Benching

Bank deposits are ordinarily mined dry by bottom benching. The choice between single and multiple benches depends, first, upon the thickness of the deposit and, second, upon the type of excavator used. Single benches cut with power shovels usually do not exceed 50 feet in height (87). For deposits of greater thickness multiple benches are recommended for power-shovel excavation. Although shovels are sometimes used with high benches (35) precautions must be taken against dangerous caving, entailing loss of life or property damage. The power shovel has no means of protection against caving from a high bank. A precautionary method often employed is to mount a small hydraulic giant on or near the shovel (22), the water from which is directed against the upper part of the bank to cut down the top ahead of excavation by the shovel at the bottom. Another method involves the use of a stream of water pumped to the top of the bank and allowed to trickle over the face and wash down the upper portion (35). In either case the water does no actual excavating but is used as an indirect aid and protection to the shovel. These expedients are successful if the gravel is not too compacted and presents no great obstacle to disintegration by water or hand-caving. If no water is available for this purpose men are often employed to bar or blast down high banks. If the gravel is very compact a thick deposit should be cut into multiple benches for power-shovel excavation.

Single, high benches permit the use of larger shovel units and require less-frequent shovel movement, thereby increasing efficiency. On the other hand, multiple benches neccessitate the use of more - usually smaller but more mobile - units, permitting more selective mining from the face; this is often of considerable advantage in providing a uniform feed to the washing plant.

Banks exceeding 50 feet in height may be excavated safely and successfully as single bottom benches by power scrapers (42, 60), even when the bank consists of heavily compacted gravel, if the tail tower is placed on top of the bank and the head tower at the base. In such a set-up the scraper effectually breaks down the top of the bank and prevents dangerous caving. In fact, it

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actually employs caving to facilitate mining. The power scraper is not used for multiple-bench operations, principally because it can excavate in a single bench such deposits as would require multiple benches with shovels.

High banks operated as single bottom benches often permit excavation without previous stripping, even though the overburden may be quite thick. By excavation from below or over the whole vertical height of the bank the overburden is caved or dragged down and mixed with the gravel. The higher the bank the less the contamination. If the same bank were worked by multiple benches the overburden would have to be stripped separately; otherwise the top bench would include all of it, which might easily destroy the value of the gravel from that bench. For example, assume a bank of gravel 200 feet thick covered with 25 feet of waste material, such as fine sand and clay. If the bank is worked as a single bottom bench the ratio of waste to gravel would be 1:8 but if worked by the multiple-bench system without previous stripping the ratio of waste to gravel in the top bench would be 1:2, and the face would be 75 feet high. In this instance material from the top bench might require a special washing treatment.

Where bank deposits must be stripped the overburden is usually removed in a single bottom bench by a power shovel (17) or by hydraulicking if water under pressure is available. Sometimes, however, the overburden is removed in a single top bench by dragline (54, 88), power scraper (32), or slackline cableway. The contour of the surface over bank deposits usually provides dumping space for overburden in ravines. Cars and locomotives or motor trucks serve the shovel or dragline, but often the power scraper or slackline cableway can dig and haul to waste in one operation. If no such waste space is available except by long haul the operator should weigh carefully the cost of separate stripping with multiple benches against a single bench without stripping, even though his washing expense may be increased by the latter combination.

Where the bottom-bench method is employed in a bank deposit the power shovel cannot strip overburden and mine gravel from the same position, as is often possible by top benching with a dragline.

Single or multiple bottom benches may be cut in bank deposits with the power shovel in straight, concave, or convex faces with equal operating facility. The shape of the face, however, will affect the haulage method. Although cars and locomotives or trucks can follow the shovel around curved faces field belt conveyors are limited to straight faces, except where specially designed pendulum or fan conveyors are used (52).

The power scraper excavates a bank as a bottom bench, usually with a concave or cone-shaped face (32, 60). It can be made to cut a straight or even a convex face, however, if the inhaul tower is moved laterally with the tail tower, but these methods are not common.

For example, assume that the deposit consists of a long but comparatively narrow ridge, such as a terminal or lateral moraine. If the head and tail towers are set up at the same elevation on each flank of the ridge with the

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cables transverse to the long axis the bench may be advanced lengthwise of the ridge and carried its full width by moving head and tail towers with the bench. The machine thus cuts a straight face.

The power scraper may be set part way up the face of a high bank deposit and work the upper half as a bottom bench and the lower half as a top bench, but this method, like the preceding example, is permissible only with suitable local conditions. Many other special arrangements might be conceived for special conditions.

Bank deposits may be worked with water by hydraulicking (3, 35, 83, 86); water under pressure is used to undercut and cave the bank in a single bench and wash the caved gravel to a sluice or pump sump for haulage to the washing plant. The bench may be worked as a straight or concave face, but convex faces are not used with this method. This system of mining is duscussed in detail in Information Circular 6814 (7), part 2 of this series of papers: Ground-sluicing in which a natural stream of water is diverted and directed against the foot of a bank, although commonly used in placer mining, is not used in mining sand and gravel.

Glory-hole methods (89), common to metal mining and quarrying (63), seldom have been applied to sand and gravel deposits. However, where the bank deposit is exceptionally thick without excess clay or boulders application of such a system is both possible and economical. The first step in installing it is to drive haulage adits or tunnels under the base of the deposit. As gravel is unconsolidated some form of shield or forepoling is necessary in advancing the adit or tunnel; the tunnel would require adequate protection by timber on the sides, top, and possibly bottom to prevent ground swelling. At intervals along the tunnel, loading chutes should be constructed to complete the preparation. The unconsolidated gravel flows by gravity into the chutes and is loaded directly into cars or onto conveyor belts without the aid of any power shovel or other loading device.

The advantage of this system is elimination of loading equipment and substitution of gravity through caving for this purpose.

The disadvantage is the necessity of constructing and maintaining timbered tunnels and loading chutes. The cost of this construction, however, should be balanced against the cost of power shovels or other loading units. If the cost of construction and maintenance is disregarded the net loading cost through chutes for unconsolidated free-running gravel is less than loading by surface equipment.

For economical operation, however, such a system requires an exceedingly thick deposit, probably not less than 200 feet. Such deposits of gravel are not commonly found as bank deposits.

Haulage with Dry Bottom Benches. - Operating a bank deposit as a single bottom bench has the advantage of concentrating all haulage operations on one operating level, whereas if multiple benches are used the haulage method must be designed to collect loaded equipment from each bench and deliver it to a main line over which it is lowered by proper grades, often necessitating long, curved tracks or switch-backs (87).

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With dry benches the power shovel may be served by cars hauled by locomotives (43, 75) or by motor trucks (17, 64). If the face of the bench is kept straight field belt conveyors may be used (35, 67) but they must be of special design with curved faces (48, 52).

Where the power scraper is installed with the tail tower on top of a high bank its head tower ordinarily is built as a part of the washing plant and it therefore does its own hauling. This, however, is not necessary; the same scraper may discharge over a ramp or hopper to any type of haulage, including cars, trucks, conveyor belt (32, 60), or even an aerial tram (21).

The power scraper or slackline cableway with both towers on the same level usually employs portable towers and loads some other unit of haulage - car, truck, or conveyor belt.

The multiple-bench system of mining limits haulage to either cars and locomotives or motor trucks.

For removal of overburden cars and locomotives or trucks serve power shovels and draglines, but power scrapers or slackline cableways used for stripping do their own hauling.

Haulage with Hydraulic Mining. - Where banks are mined by hydraulicking the giants wash the excavated gravel either to sluices (76, 84, 85), which carry it to the washing plant, or to sumps cut in the floor, from which dredge pumps pick it up and transport it through pipelines to the plant (90).

Hydraulic mining and transportation have the advantage of disintegrating and washing the gravel more or less thoroughly before it reaches the plant. This is of major importance when the gravel deposit contains a large quantity of clay. On the other hand, water transportation through sluice or pipeline is difficult if the deposit contains more than 10 percent of boulders. These must be removed either at the face or at some other point between the face and entrance to the sluice or sump. Hydraulic giants are not adapted to moving large boulders; usually some other equipment, such as a crawler crane, is installed for this purpose.

Sluices are suitable for haulage only when the deposit is worked at an elevation above that of the washing plant. Dredge pumps and pipelines, on the other hand, can transport the material over level ground or even elevate it directly to the top of the plant (66).

Both hydraulic mining and hydraulic transportation require large quantities of water, preferably from a source above the gravel deposit. Water from a higher elevation, however, is seldom available for bank deposits and must therefore be pumped; pumping adds to the expense, as discussed in part 2 of this series (7).

Top Benching

Excavation of bank deposits by top benching with single or multiple benches must, for purely physical reasons, be conducted without the aid of

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water. Water could be cascaded over a bank, as is sometimes done in ground-sluicing placer deposits, but the level on which the gravel is recovered would be below the bench and hence by definition the system would be bottom benching. Neither can wet mining be employed, as in pit deposits, because the bank extends above the level of the surrounding land surface and there is nothing to retain water. Hence, top benching of bank deposits is always a dry operation.

Top benching as applied to bank deposits must not be considered ordinary practice; it is applicable only under special local conditions, which make it analogous to pit mining by the same method.

One of the two principal advantages attributed to bank deposits is that the mined material is hauled over level tracks or downgrade to the treatment plant. This is modified if the top-bench method of mining is used, inasmuch as the bench is excavated from above and the excavator necessarily must elevate the gravel, although actual haulage may still be level or downgrade to the plant. Elevation of the gravel to the top of the bank usually requires more power than is used in bottom benching. A power shovel cuts and elevates each dipperload, but the total lift is less than by top benching unless the bench height is less than the shovel lift. In top benching each bucketload must be lifted the full height of the bench. In spite of the increased power cost a combination of circumstances may make it advisable to mine certain bank deposits of sand and gravel by top benching.

This method probably is most applicable where the deposit covers a broad elevation or plateau, such as a coastal plain or the high bank of a long extinct watercourse, and the treatment plant must be located on top of the bank or plateau because of property lines or other reasons. Top benching is a logical solution of such a combination, and at once the analogy with topbenching a pit deposit becomes apparent.

Either single or multiple benches may be worked in top-benching bank deposits, and bench faces may be straight or curved, convex or concave. As the bench is excavated from the top the danger of property damage from caving banks is reduced although not eliminated. If the excavating machine is moved too near the edge of an unconsolidated bench there is always the possibility that its weight will cause the bank to give way and overturn the excavator.

Power shovels and hydraulic giants are unsuited for top benching because they have no means of elevating material. This statement must be modified to include shovels with long boom and dipper stick loading cars on top of the bench. Such operations are possible with low banks only and must be classed as special conditions. The equipment most commonly used for top benching includes the dragline, power scraper, and slackline cableway. Of these the dragline is the only one that approaches the edge of the bank and hence is subject to danger from caving. The head towers of both the power scraper and slackline cableway are set far enough back of the crest of the excavation to obviate any danger from this source.

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Stripping and mining over the same area in a bank deposit by top benching can be done from the same setting of the head towers of either the power scraper or the slackline cableway. If both operations are performed by the same unit the overburden must be loaded into haulage equipment for disposal, but if separate units are used the stripper usually can be located so that it can excavate and haul the overburden direct to the waste dump, which may be a ravine or an elevated waste pile. Where one unit does both stripping and mining the tail towers must be set for each operation, hence both cannot be carried on simultaneously. Using the same mining method but excavating by dragline a single unit can both strip and mine from the same position by alternating from one operation to the other. Moreover the dragline can load overburden to haulage equipment or cast it to the excavated area behind the gravel bank. Thus, this unit can cut two benches from the same position. This process carries stripping concurrently with mining and constitutes the most common application of the use of multiple benches to top-benching a bank deposit. The author is not aware of any operation in which two or more distinct benches of gravel are mined by top benching, although no mechanical difficulty seems to be involved. For example, an extremely thick bank probably could be mined in benches or steps by dragline, similar to the use of shovels on terraced benches. To a limited extent this method is employed in pit mining, as explained later.

Bank mining by single top benches must be done after the overburden has been stripped, or the overburden must be mined with the gravel. If the overburden is removed first it may be done by bottom benching with a power shovel or hydraulic giant; it may also be stripped by top benching by dragline, scraper, or slackline. After stripping, either of the three excavators may be used to remove a single top bench.

Reference to table 10, part 1, of this series (6) shows that the maximum depth below grade that a dragline can reach ranges from 5 to 107 feet with standard cable equipment. However, all draglines can be fitted with longer ropes if necessary for deep excavation. The probable average bench height for dragline top benching would not greatly exceed 50 feet, although in specific instances it might be double that distance or more. The depth to which power scrapers will operate ranges from 10 to 20 percent of the maximum span and for slackline cableways from 20 to 25 percent of the maximum span (7).

Haulage with Top Benching. - In top-benching a plateau or old river bank where the treatment plant is level with the top of the bench or at the base the haulage unit proceeds over level track or downgrade, as in bank mining. The excavation equipment, however, must elevate the gravel from the foot to the top of the bench. In this type of deposit the treatment plant is sometimes higher than the excavating equipment, in which case the haulage unit must operate upgrade - the exception noted in foregoing pages. This arrangement is not common in actual practice.

The dragline may be served by cars and locomotives, motor trucks, or field belt conveyors if the bench faces are straight. If they are curved, belts can be used only with difficulty. The power scraper and slackline cableway usually serve also as haulage units and need no similar service

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equipment. If, however, the operation requires mobility in the head towers as well as tail towers additional haulage units must be introduced between scraper or slackline and plant. Cars, trucks, or belts can be used for this purpose, depending upon local conditions.

In that method of multiple top benching in which a single dragline strips overburden and mines gravel concurrently the method of haulage varies. The overburden and gravel may be loaded into different cars in the same train, separate trains on the same track, separate trains on different tracks, or separate trucks. Overburden may be hauled by trucks and gravel by cars or vice versa, or the gravel may be delivered to hoppers feeding a field belt conveyor. The overburden may also be cast to the excavated area without requiring haulage equipment.

Pit Deposits

Pit deposits are subdivided into dry and wet pits according to the presence or absence of subsurface or ground water. Virtually all dry pits are mined by methods similar to those used in bank mining. Methods used in wet pits differ materially from bank mining, although similar equipment may be used. In pit mining, whether dry or wet, the material must be elevated, usually to a point above its natural position. The possible presence of ground water and the necessity of elevating the material are the chief differences between pit and bank mining.

Pit deposits are mined by bottom benching with power shovels (33), power scrapers (21), or hydraulic giants; by top benching with cranes (51), power scrapers (12), or slackline cableways (49); or by dredging (28). The latter, however, may be similar to bottom benching, depending upon the relation between the elevation of the water surface and that of the top of the bench or ground surface.

Dry Pits

Bottom Benching. - In mining dry-pit deposits by the bottom-bench method the excavator in most common use is the power shovel. The hydraulic giant sometimes is used and, in rare instances, the power scraper. As the material must be elevated from the pit and the scraper can do the elevating obviously there is little economy in using this type of excavator to drag gravel down the bench and then elevate it by other means. Under certain conditions, however, this procedure may be justified (21).

Whatever type of excavator is used provision must be made for dewatering the pit in case of flooding or heavy rains.

Power Shovels. - Either single or multiple benches may be cut by the shovel, depending upon the thickness of the deposit. With thin overburden over a 50-foot deposit stripping is often unnecessary (18, 27, 58). Thick overburden may be removed as a single bottom bench followed by a similar bench in the gravel - a multiple bottom-bench method (22, 70). In the same

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type of deposit the overburden may be removed by top benching, although the bottom-bench method is retained for mining gravel (25). Thus, both top and bottom benching may be used in the multiple bench system. The same combination may be used in thick deposits having more than one bottom bench in the gravel.

In the initial stage of opening a pit deposit the shovel cuts a bottom bench with a concave face, but as the pit is enlarged the face may be straightened (16) or even curved to convex form. Straight faces often present an advantage in following property lines, whereas concave faces are an aid to one-way circular or elliptical haulage. Convex faces have no particular advantage in gravel mining, except where local conditions require their use.

Hydraulic Giants. - Pit deposits can be mined by hydraulicking in the same manner as bank deposits. Preliminary stripping may be done by bottom benching with shovel or hydraulic giant or by top benching with other equipment. Material mined by hydraulicking must be dewatered before being loaded into haulage units, or it must be sluiced to a sump and pumped out of the pit. Hydraulic mining by ground-sluicing is not used for gravel deposits.

Glory-Hole Mining. - The glory-hole method, so far as the author is aware, is not employed in gravel pits. The principal objection to the use of this system is the heavy expense involved in sinking the necessary shaft and driving haulage tunnels under the deposit before mining. Owing to the ground water in most pit deposits it would be extremely expensive to keep haulage openings clear of water.

Top Benching

The top-benching system of mining dry pits with draglines, power scrapers, or slackline cableways is probably more common than bottom benching. It eliminates the necessity for constructing haulage grades from the ground surface to the pit bottom and the movement of heavy machinery into the pit. It also permits operations to continue even when the deposits are flooded by heavy rains because excavating equipment suitable for this method can operate in a flooded pit whereas bottom benching would be prevented until the flood water was removed.

In preparation for top benching dry pits may be stripped of overburden with the same equipment as is used for mining the gravel (44, 55, 66) or separate equipment as local requirements dictate. If the overburden is relatively thin separate stripping may be eliminated and the overburden removed with the gravel in a single bench (12, 16, 53). If it is thick the stripping may be done by bottom benching with a power shovel followed by top benching with any of the three excavators mentioned. In mining gravel from dry pits multiple top benches are seldom used except where the overburden is removed in a separate operation.

Dragline. - Top benching with draglines is common and economical. The dragline can strip overburden from a small area and cast it beyond the toe of the gravel bench in the excavated pit and then without changing position mine the gravel from the stripped area (55, 66). Thus, the dragline can take

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advantage of delay caused by the absence of haulage equipment to strip ahead of mining without loss of time. It also can carry a higher bench than the shovel without danger from caving so long as it remains far enough from the edge of the bank. In mining excessively deep pits (77) with single high benches time is lost in individual bucket cycles owing to the length of the drag cable. Extra-long cables usually require more than one wrap on the hoist drum and show corresponding wear due to abrasion.

If the overburden cannot be conveniently cast to the excavated pit the dragline can dig and load it to haulage units, as it does gravel, and still carry a multiple-bench system from a single position. Where the overburden is thin the dragline can remove both overburden and gravel as a single bench (53). Sometimes one dragline removes thick overburden and casts to the excavated pit, while a second dragline mines the gravel in a second top bench. Again, the stripping may be carried as a top bench by power scraper or slackline cableway followed by the dragline mining a top bench in the gravel.

When the overburden is stripped by a separate, similar, or different machine stripping may be carried on simultaneously with mining but over different areas. The dragline is the only machine that can be used to strip and mine concurrently from the same set-up. This is an advantage peculiar to the dragline in top benching.

Power Scrapers. - The power scraper is frequently used to strip and mine pit deposits (44) but both operations cannot proceed concurrently, as with the dragline, without contamination of the gravel with overburden. Mechanically, however, such a plan is possible but impracticable. The usual procedure with power-scraper operation is to set up the unit and strip a predetermined area, either piling the overburden in a single waste dump or loading it to haulage units. From the same position the gravel is then dug from the stripped area. Thus, the actual operation is alternate stripping and mining from the same set-up, but all the overburden must be removed from a given area first and the gravel later, whereas the dragline can remove either in small batches concurrently.

The power scraper can strip overburden and drag it to the pit from which gravel has been removed, but in so doing it contaminates the gravel face, and some gravel is lost. The amount so lost, however, is negligible.

By reversing the direction of haul the power scraper may be used to strip gravel and dump it around the tail tower and later dig and haul the underlying gravel to the head tower. By this method the bucket must be returned mechanically, and gravity return cannot be utilized.

Power scrapers are not suitable for multiple benching, except as the term may be interpreted to mean stripping by a single bench and mining by another similar bench over the same area.

In most installations the head tower of a power scraper used in pit mining is stationary, although the face cut in the bench is straight for each position of the tail tower the composite face produced by numerous cuts

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is fan-shaped or concave. Convex faces are seldom necessary and of no particular advantage. Where the head tower is moved with each fresh cut the bench is carried with a straight face, but in this type of operation the scraper must be served by some form of auxiliary haulage unit.

Slackline-Cableway Excavators. - The slackline-cableway excavator mines a dry-pit deposit by top benching in much the same way as the drag scraper (16, 36, 42), except that the direction of haul cannot be reversed because the slackline depends upon gravity to return the empty bucket.

The slackline has an advantage over the scraper in that the bucket is raised above the surface on the inhaul and can be used to strip one portion of the deposit and dump the overburden in an excavated area without contaminating the gravel face.

Bench faces are straight or fan-shaped, as when cut by a power scraper.

The slackline, by carrying the loaded bucket high in the air, can often avoid obstructions in the line of travel that would have to be removed for power-scraper operation.

Dry-Pit Haulage. - The type of haulage selected for a dry pit is a fundamental factor in determining whether the pit is to be mined by bottom or top benching. For example, if top benching by dragline is selected the haulage route may be of minimum length - direct from the dragline to the treatment plant. Excavation by bottom benching with a power shovel from the same point in the bench might require a long, circuitous haulage route to provide the grades that would enable the haulage unit to ascend from the bottom to the top of the pit and possibly additional surface haul around the perimeter of the pit. The cost of this excess haul can easily represent the difference between profit and loss in pit operation.

With equal length of haul for both systems the type of haulage used will still be an important factor in the selection of the mining method. For example, a power scraper or slackline cableway may excavate material from a certain point in a pit and haul it direct to the plant on the surface over a distance equal to that required by a truck or locomotive serving a shovel at the same point. The power scraper excavates, hauls, and elevates with one movement, whereas the shovel excavates only and the truck or locomotive must haul and elevate. Thus, the scraper or slackline requires no initial investment for service haulage equipment or roadway grading, and maintenance and capital charges may be reduced considerably, with corresponding reduction in operating costs.

On the other hand, the distance between excavation point and treatment plant may be too great for the single span of a power scraper or slackline. The problem then resolves into balancing the efficiency of two scraper units, one used solely for haulage, against a shovel and locomotives or trucks.

Various other combinations of circumstances might be cited, but in all the selection of the haulage method has a direct bearing on the mining system (70).

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Bottom Benching. - The common methods of haulage from bottom benching by power shovels utilize cars and locomotives (13, 27, 58) or motor trucks (34). Either method may be used to take material from the shovel and deliver it direct to the treatment plant; also either may be used in conjunction with other types of haulage.

With direct haul by either method the track or roadway must be built on suitable grades to enable the unit to ascend from the bottom to the top of the pit. As the maximum grade for either type is fixed the length of haul will increase as the pit depth increases. The maximum grade for locomotives will be less than for trucks; hence, for the same pit depth the haulage distance for a locomotive will be greater. As pit depth increases in proportion to the area of excavation the space required for maximum haulage grades decreases until in some instances recourse to curved routes or switchbacks is necessary to obtain the required length. Obviously added length of haul increases the time cycle of the haulage unit and reduces its capacity; moreover, increase in depth adds to the power expended in bringing material out of the pit.

In many pit operations the relation between depth and area is such as to prohibit the use of long, circuitous haulage routes for either locomotives or trucks. The difficulty is frequently overcome by retaining either unit to serve the shovel but restricting its operation to the pit floor. Either delivers to the foot of an engine plane (22) or to an inclined field belt conveyor (52, 70). The engine plane may use the same cars as the locomotive, or it may use specially designed skips hoisted in balance. The selection of long, graded haulage routes or the more direct level route supplemented by inclined belt or plane should be made wholly on the basis of local conditions; no general recommendations can be made without assuming special conditions.

Haulage in dry pits in which the gravel is mined by hydraulicking is usually accomplished by the installation of a dredge pump over a sump dug in the floor of the pit. A hydraulic giant washes the gravel to the sump through ditches or sluices, and the pump picks up the water and gravel mixture and delivers it to the plant through an appropriate pipeline.

Because of the nature of hydraulicking and the large volume of water used, the dredge pump and pipeline are the only logical mode of transportation. The use of other types would involve some means of dewatering at the sump as well as pumping the excess water out of the pit. This excess water cannot be safely pumped for reuse at the giant without careful settling or filtering to remove sand and gravel; otherwise the wear on the nozzle would be excessive.

Top Benching. - The haulage problem from dry pits using the top-benching system is comparatively simple. If a dragline is used it is served either by cars and locomotives (53, 55, 66) or by motor trucks, and the haul is by the most direct route over a comparatively level roadway to the plant.

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The power scraper and slackline cableway are often built with their head towers integral with the treatment plant (36) and hence solve the haulage problem at the start by delivering direct to the plant. If the head tower is not a part of the plant other haulage equipment may be used (12, 44, 51). With movable head towers either locomotives and cars or trucks may be used to supplement the scraper.

General Comment. - From the preceding discussion of methods used in mining dry pits it is obvious that the selection of method, excavator, and haulage unit is not simple. All three depend somewhat on each other. For example, a choice between bottom benching with power shovels and top benching with dragline must balance the economic effect of possible long curved and graded haulage routes in gaining elevation against the direct lift of the dragline. This is a matter of installation and maintenance cost and power used. Theoretically, equal power is consumed as the same amount of material is lifted the same vertical height. Practically, however, the power consumption by the dragline is probably less - certainly so if the haulage route is long because of the power consumed by friction losses in journals and between wheels and tracks or the extra fuel consumption over longer routes.

Wet Pits

All material lying below the surface of the ground contains water. If the material is porous and the subsurface drainage good the water may be present merely as moisture, but if the material is impervious and the drainage poor the deposit may attain a saturated condition. Where subsurface drainage is adequate to carry off all ground water to some point below the lower limit of the gravel the deposit may be worked as a dry pit; where such drainage is insufficient the deposit becomes a wet pit and must be worked as such unless artificial drainage can be supplied.

The method used in mining a wet pit depends largely upon the elevation of the water table, but the quantity flowing also should be considered. To clarify this point a discussion of the physical formation of pit deposits is necessary in order to visualize and understand the reasons for a changing water level.

In an earlier paper (4) the author pointed out the necessity for observing the water level in test pits and also the rapidity with which they filled to that level after having been pumped dry. The subsurface flow can thus be gaged approximately. Both surface elevation and flow are important, as will be shown later.

Gravel deposits may themselves be virtually impervious to the passage of water or they may be porous and offer very little resistance to percolation, depending upon the amount of clay or other impervious matter present to fill the voids between sand and gravel particles. All gravel deposits are surrounded by other materials of different physical properties. The enclosing strata may be impervious, or porous, or have open watercourses. Obviously, the rate of migration of ground water through both the gravel and the surrounding

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strata will vary greatly in different deposits. Those containing clean, loose gravel with little fine sand and surrounded by strata of open structure will hold little water and can be worked as dry pits. Those containing large quantities of clay or fine sand and surrounded by impervious strata will contain gravel saturated with water. Pits or holes drilled in this type of deposit will be full of water at all times. Between these two extremes lies a large group of combinations affecting both water level and subsurface flow. They are all wet pits, but their water content will range from nearly dry to saturation and from a light flow to a very heavy one.

A more or less impervious gravel deposit may be filled with water during the spring season and because of its physical density give up that water with difficulty, hence the ground-water level drops slowly.

A loose, clean deposit surrounded by an impervious stratum will fill in the spring, and the water level will drop only as the surrounding material permits drainage.

The material surrounding a deposit of gravel may be impervious at lower elevations and porous above. Under these conditions a clean, loose gravel might drain freely near the surface, even during wet seasons, but would remain saturated below the level of the impervious stratum through a prolonged dry spell.

The degree of porosity of the gravel and the material surrounding it will determine the rate of subsurface flow. This cannot always be determined by shallow test pits in and around the deposit. For example, a deposit containing considerable clay and with its upper part surrounded by clay, as shown by test pits, would indicate a condition favorable to a stable water level. However, open passages below or porous material surrounding the lower part of the deposit - not penetrated by test drilling - might easily upset such conclusions. Plans for dredging such a deposit would be economically fatal because of eventual but slow loss of water.

Many other combinations might be mentioned, but these few illustrate the variety of conditions found in wet pits and the need of as exact knowledge as possible before the mining method can be intelligently selected (80).

Bottom Benching. - The bottom-bench system for wet pits is limited to stripping overburden (16) or removing that portion of the gravel lying above the permanent ground-water level (37). In either case the method is exactly the same and utilizes the same equipment as in bottom-benching dry pits. In fact, it is dry-pit mining. A possible exception or modification will be discussed under dredging.

Top Benching. - Wet pits are commonly mined by top benching. The methods and equipment are the same as for dry-pit mining, except that an excavator crane equipped with clamshell or orange-peel bucket is frequently used. Ground water or the elevation of its surface in the pit makes little difference, as the dragline, power scraper, slackline cableway, or crane operates under water with comparative facility. The rate of subsurface flow also has no effect on top-benching methods with the types of equipment mentioned.

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Overburden may be removed by bottom-benching, as previously stated (16), or it can be stripped by a separate single top bench (9, 20, 28, 33, 39). With wet-pit operation, however, there is less need for separate stripping of even thick overburden (31) because it can be caved into the water and washed fairly well as it is brought up with the gravel (10, 23, 57). If necessary the dragline can strip and cast to the water in the excavated pit beyond the gravel bench (59, 62). The power scraper and slackline excavator can also strip and cast overburden to excavated areas. (See Dry Pits - Top Benching.)

In those pits in which the water level is below the top of the gravel the upper portion may be mined by top benching, the material being taken both from below and above the water in a single bench (24, 57).

In some deposits material lying above the water level may differ physically from that below, or it may be desired to mine that above and keep it dry. Multiple top benching is then the solution. The dragline removes the overburden first and casts it to the excavated pit. It next mines a second bench down to the water level and finally a third bench from below the surface. The power scraper and slackline cableway also may be used for this purpose, but the area of each bench will be increased (69). The crane can restrict the amount taken from each bench to a single bucketload (13).

On the other hand, in stratified deposits containing clay single-bench mining is often an advantage in wetting all material thoroughly and mixing that from different levels before it is sent to the plant (2).

Benches may be straight or curved, convex or concave, as surface topography or local conditions warrant.

Dredging. - Dredging is primarily top benching, as the dredge removes material from below the surface of the water on which it floats. However, in a wet pit the water level is frequently some distance below the top of the bench; hence, the dredge actually excavates from the bottom, as does a shovel in bottom benching. For this reason dredging has been classed in the chart as intermediate between bottom and top benching. It approximates bottom benching as the water level approaches the bottom of the gravel deposit and resembles top benching as the water level approaches the top of the gravel.

Wet pits may be mined by any type of dredge (8), although the hydraulic dredge (13, 14, 16, 28, 46) is by far the most common. Ladder (41) and clamshell dredges are frequently used in wet pits, but the dipper dredge is seldom used for this type of deposit.

It is of utmost importance to know the rate of subsurface flow of ground water before installing a hydraulic dredge in a wet pit. As the dredge ordinarily pumps a mixture containing approximately 10 percent solids and 90 percent water by volume it will remove 9 cubic yards of water with 1 cubic yard of sand and gravel from the pit. This excess volume of water must be

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supplied by subsurface flow through the gravel and surrounding strata. Failure to measure the flow before the dredge is installed may mean serious financial loss. Instances have been known where pump dredges installed without adequate water flow had to be abandoned for other equipment.

The rate of flow does not affect the operation of a clamshell, ladder or dipper dredge except during seasonal changes.

With either type of dredge the method, whether classed as bottom or top benching, is carried as a single bench. Multiple benches are not used.

Faces may be straight or curved, convex or concave, as local conditions indicate, but there is little advantage in any one shape over another as far as economy of operation is concerned.

Hydraulic giants are frequently mounted on dredges (16), and the stream is played on the bank to cave it ahead of the dredge. This safety precaution is the same as that used to cave a high bank ahead of a power shovel.

Wet-Pit Haulage. - Haulage equipment for wet pits is the same as that for dry pits when bottom-bench methods are used (16, 37). If dry-land excavators are used with the top-bench method the haulage methods and equipment are also similar to those for dry pits because only the excavator bucket enters the water, and it delivers its load to the haulage unit or plant on land (9, 15, 24, 44, 68, 69).

With dredging, however, two types of haulage are necessary. Hydraulic dredges frequently use the dredging pump to do double duty - to dredge and to deliver dredged material through pipelines to the plant on shore (13, 16, 19, 24, 28, 46). In compacted material a dragline has been used to break up and excavate the gravel and deliver it to the suction of a dredge pump for delivery to the plant (72). If the distance or elevation is too great for the dredge pump to handle the discharge, booster pumps often are inserted in the discharge line (47). A booster pump may be installed on a floating scow or placed at some point in the line ashore. In some recent installations the dredge pump is used to pump material through a floating pipeline to a shore station where the gravel and sand are dewatered by screens or other means and then carried to the plant by field conveyor belts (61). Trucks or cars can be used for the same purpose after the pump discharge has been dewatered. For haulage from distant points in large pits towboats and barges (14) are sometimes used, although less frequently in wet pits than in marine deposits. The barges are seldom of the self-unloading type but depend upon shore equipment to transfer their cargo to further conveyance or plant on shore. Shore equipment for this purpose is usually a clamshell crane mounted on a permanent or crawler base. A few self-unloading barges are equipped with conveyor belts which receive their load from the bottoms of cargo hoppers and discharge to other conveyors on the dock (14).

The haulage equipment used to serve ladder dredges is always some type of towboat and barge (41). Although frequently used for placer mining in wet pits

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and for marine gravel deposits the ladder dredge is not often employed for gravel production from this type of deposit.

General Comments. - Inclusion of the dredge as an excavating machine enlarges the field from which a choice of methods may be made for wet-pit mining. Haulage is also augmented by the addition of the floating barge. On the other hand, the bottom-bench method is restricted to stripping or removing material from above water level, except as dredging pits with high banks may be so classed. Top benching in single benches from land or by floating equipment is the method commonly used.

The depth of water in the pit and the elevation of its surface with respect to the top of the bench have little effect on the efficiency of dry-land excavators mining wet pits. Dredges require enough water in the pit to float them, and hydraulic dredges require a large enough subsurface flow to replace the water removed in dredging.

Material mined from wet pits is saturated with water and may require changes in details of construction of haulage equipment other than would be necessary with dry material.

Sand and gravel from wet pits, especially if dredged by hydraulic dredges, are partly washed during the process of excavation. This method enables the operator to avoid the expense of stripping by mixing the overburden with the gravel, and it reduces the wash-water requirements at the treatment plant.

Either top-benching or dredging a wet pit tends to mix the material from all parts of the bench thoroughly and thus provides a more uniform product as feed to the treatment plant.

Marine Deposits

Marine deposits have similar characteristics, irrespective of the body of water under which they lie, but for convenience, they are subdivided into river, lake, and ocean deposits. By definition, river deposits include the bed, bars, and small islands between the natural banks of the river. Lake and ocean deposits might be similarly defined but are usually restricted to beds and bars.

Subaqueous mining is the most common method of covering gravel from marine deposits. There are some exceptions in river beds, as will be noted.

Excavation equipment for this method of mining is restricted to some type of dredge, but its design may differ materially from a similar type used in wet pits (56). For illustration, dredges used in marine deposits must be designed to withstand floods or wave action during storms and to operate in stream or tidal currents and under changing depth conditions due to the rise and fall of tides. For ocean deposits they must be designed to resist the corrosive action of salt water.

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Haulage equipment must, in general, be seaworthy, and the selfpropelled barge is used extensively.

Therefore while methods and equipment used in marine deposits are similar to those used in wet pits they may differ materially in detail.

Where currents are troublesome, dikes sometimes are built between islands or between an island and the river bank, behind which dredges may mine the river bed under conditions simulating those of wet pits (31). Similarly, a lake or ocean dredge may abandon the subaqueous bed and cut its way from open water through the beach into a shore extension of the bed (1).

River Beds

River beds and small islands may be mined by top benching with power scrapers (71) or slackline cableways (73) located on the river bank, by dredges floating on the stream (11, 65), or by both (74). Dredges used in riverwork are often called upon to mine beds at widely scattered points. Because of the necessity for this extended mining range there is greater preference for towboats (26) and barges as the transportation medium. In addition, many dredges used for riverwork are designed to include washing and screening equipment and thereby avoid hauling waste products over long distances. Preference is thus given to barge haul.

Top Benching. - Although dredging in a river bed is technically top benching the removal of an island deposit by dredging might be classed as bottom benching. Therefore to avoid confusion the term "top benching" used in connection with marine deposits will be limited to excavation by power scrapers or slackline cableways operated from the river bank.

Top benching by these two units may be further subdivided, depending upon whether the excavator is permanently located on the bank (10) or is free to move. Stationary equipment usually is built with the head tower integral with the washing plant; movement is therefore difficult. Occasionally the head tower and plant are designed as portable equipment. Permanent plants are limited in operating life to the time required to exhaust the bed or bar within reach of the scraper or slackline. In some rivers during times of flood the area excavated is refilled by new gravel brought down by the river itself (10, 71). Permanent plants so situated are fortunate in that no new deposits need be sought and moving expense is eliminated. In other instances when the permanent plant has exhausted material within reach, the scraper may be left intact and a dredge installed to dig distant bars and deliver by barge to the scraper (74). The dredge takes the place of river floods in supplying the scraper with new gravel.

Movable plants may be portable as regards the scraper or slackline only, or the whole washing plant may be portable. In the latter case the whole plant is moved to a new location when a bar is exhausted, and the only additional change required is an extension of highway or shipping track. If the excavator only is portable the scraper or slackline is moved to a new location when the bar is exhausted, but auxiliary haulage units must be installed to serve the excavator and deliver to the plant (71, 73).

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Draglines have not been mentioned in connection with river-bed excavation because of their limited reach from the river bank. They may, however, be used to mine an island deposit and load barges moored to the bank. To warrant such equipment the island would have to be large; the operation would then approach wet-pit mining.

Top benching by scrapers or slackline is common practice in mining river deposits. The head tower is set on one bank and the tail tower either on the opposite bank or at some point in the stream - on an island or exposed bar, directly in the river bed, or on a floating scow anchored at will. The method of operation is the same as for wet pits. If the stream is navigable the use of high towers on a slackline may avoid interference with navigation, whereas a scraper would be confined to an area outside the river channel.

The stationary plant, whether scraper or slackline, cuts a fan-shaped top bench with concave face. The movable plant, however, may carry a straight face upstream or downstream as desired, or it may excavate a series of fan-shaped benches.

Dredging. - Customarily, river bars are dredged selectively. Because of the sorting action of running water river bars contain materials of different gradation. Thus, one bar may contain a relatively high percentage of gravel and another a high proportion of sand. Hence, the dredge is frequently alternated between several bars, according to the type of material needed for market. The dredge therefore is set over a bar and digs without regard to continuation from a previous excavation or any systematically laid-out scheme of excavation. If the bar is extensive and the material uniform the dredge may operate systematically by cutting straight or curved slices consecutively from one side, like a power shovel in dry-pit mining. To maintain this type of systematic dredging, points must be set on shore or by anchored buoys, preferably along the line the dredge is to move. The dredge operator uses these sight lines to guide him for each advance of the dredge. If the deposit is an exposed bar, the bench face of which can be seen, such sighting points are, of course, not required.

Types of Dredges. - The hydraulic dredge is probably the most popular for river deposits. Where large tonnages are required from extensive bars the ladder dredge (40) rivals the hydraulic or pump dredge. In fact, the ladder dredge finds its greatest field of use in this type of gravel deposit. Grapple or clamshell dredges (40, 74) are used principally in excessively deep water or where boulders or logs would make the use of hydraulic or ladder dredges difficult. Dipper dredges have been used for gravel mining only in a few instances and were selected because of the large number of boulders in the deposit (42).

The four types of dredges and their characteristics have been described in part 3 (8) of this series of papers and will not be discussed here, except to say that hydraulic and grapple dredges are better suited for selective mining and ladder and dipper dredges for systematic mining.

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River-Bed Haulage. - When power scrapers or slackline cableways are used to top-bench river deposits the excavator itself acts as the haulage unit unless it is portable and requires the service of other equipment to complete delivery to the washing plant (71, 73). This auxiliary equipment may consist of cars, trucks, or conveyor belts, which usually operate over fairly level surface.

Where permanent plants have exhausted material within reach and actual excavation has been delegated to supplementary dredges, transportation usually is by towboat and barge, but it may be by pump and pipeline if the dredge is hydraulic. Many of the barges used are self-dumping (74); they are loaded at the dredge, towed to the site of the power scraper or slackline, and dumped to the river bed from which the bucket transfers the gravel to the shore plant. If the dredge is hydraulic and the distance not too great it may pump gravel direct to a point within reach of the scraper.

Ordinarily the distances are too great for the dredge pump to act as a transport unit also. However, in opening a new bar a hydraulic dredge may deliver direct to the shore plant, as did the power scrapers cited. If the bar is extensive and the resistance grows too great for the dredge pump to both transport and elevate to the shore plant a second dredge may be installed at the shore near the plant. The original dredge, relieved of elevating the gravel, can pump direct to the second dredge, which thus acts as a booster, or to water storage within reach of the second dredge. The second dredge then acts in the same capacity as the stationary scraper previously discussed.

Strictly speaking, a scraper or dredge used in the latter manner should be classed as a part of the treatment plant rather than a supplementary haulage unit, because its function is primarily to supply the plant rather than serve the excavator. If the first dredge pumps direct to the second and the latter acts merely as a booster it is, of course, part of the transportation system.

Various other types of transportation may be combined (73). For example, at one plant a hydraulic dredge excavates and delivers gravel to a sump from which it is elevated by a clamshell crane to a washing plant, transferred from there by belt conveyor to an aerial tram, and carried by the tram to the shore plant (31). Such combinations, however, are unusual and are used only when local factors require them.

As stated, hydraulic dredges sometimes pump from river deposits direct to the shore plant, but customarily they are served by barges (56, 65).

Ladder, grapple, and dipper dredges require barges as haulage equipment. In some instances the barges are self-propelled and fitted with self-unloading equipment.

Both dredges and haulage units used in mining river deposits frequently are required to operate in very shallow water (65). For this purpose pump dredges have been designed to work in places where the maximum draft was 2 feet or even less. Barges, however, seldom are used in less than 4 feet of water.

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Lake Beds

The mining of lake gravel beds is restricted to the use of hydraulic, grapple, or dipper dredges, named in the order of popularity. Dipper dredges are probably used more frequently for dredging ship channels through shallow lakes but seldom for gravel mining.

As in river beds, either dredge may mine selectively or systematically; in the latter method faces may be straight or curved as desired, with little advantage either way.

Ordinarily ladder dredges are not seaworthy enough for lake operation, although they may be so used under sheltered conditions.

Hydraulic dredges designed for lake operation are seldom built solely for excavation purposes (50). In this type of work they are often fitted with washing and screening equipment so that they may at least partly prepare the sand and gravel for market (30). In fact, some such dredges have been designed to function not only as excavators and complete washing and screening plants but also as haulage units (45); they are mobile treatment plants capable of proceeding to the deposit, pumping a load to their cargo hoppers, and preparing the material for market while returning to port.

Grapple or clamshell dredges as well as dipper dredges are used in lakes, principally for channel and harbor excavation rather than gravel mining.

Lake Haulage. - Unless a hydraulic dredge is mining a deposit within pumping distance of the shore plant or is itself the haulage unit all lake transportation from deposit to shore is done by tugs and barges. The flat-bottomed, stern- or side-wheel-propelled towboat, such as is used in river transportation, is unsuited for lake transportation. Round-bottomed, screw-propelled tugs are the common form of motive power. Barges may be the hopper, semihopper, or flush-deck type; the flush-deck type, however, is less common because it is less seaworthy. Semihopper or full-hopper barges are the usual equipment and are employed with all types of dredges except the self-propelled plant type.

A self-propelled, self-unloading type of vessel has been designed for long lake hauls; this is essentially a lake cargo steamer fitted with self-unloading machinery. This type of vessel, however, is used primarily in interplant rather than intraplant haulage and is not included under lake haulage, as discussed in this paper.

Ocean Deposits

Gravel deposits in salt water are mined only in sheltered bays, channels, or harbors (1). The discussion of lake operations applies equally to salt-water deposits, except that for the latter the equipment must be designed to resist salt water and units should be even more seaworthy than for lake use.

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Ladder dredges are used for gravel mining only under very sheltered conditions, hydraulic dredges are common, grapple and dipper dredges are used mostly for channel and harbor excavation, tugs are seagoing, and barges usually are the round-bottom, full-hopper type.

Equipment Costs

It is not the function of a Government bureau to quote selling prices for mining equipment. Frequently, however, an operator desires to know approximate costs from which he may estimate the probable relative expense involved in applying different methods of mining or types of equipment. For such purposes a rough indicator is useful; to supply such an indicator the following tables have been compiled from data received from manufacturers up to July 1935. The indicators represent new equipment in all cases, as it obviously would be impossible to tabulate indicators for used equipment.

Power shovels

Gasoline or single electric motor drive

Dipper size, cubic yards	Weight range, tons	Price per pound working weight		Extra per unit for Diesel power (average)
		Range	Average	
3/8	8 - 10	$0.20 - $0.28	$0.245	$850
3/8	12 - 14	.21 - .27	.230	895
1/2	12 - 16	.20 - .24	.220	825
1/2	16 - 24	.13 - .20	.165	955
3/4	17 - 22	.20 - .26	.225	1,030
3/4	22 - 34	.16 - .22	.180	1,000
1	27 - 42	.14 - .21	.175	1,500
1 1/2	39 - 53	.16 - .21	.180	1,860
2	50 - 64	.18 - .21	.200	3,520

Power shovels, Diesel or multiple electric motor drive

3 - 5	140 - 240	0.15 - 0.19	0.175	---

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Draglines

Gasoline or single electric motor drive

Bucket size, cubic yards	Weight range, tons	Price per pound working weight		Extra per unit for –	
		Range	Average	Diesel power (average)	Bucket (average)
3/8	7 - 10	$0.20 - $0.29	$0.245	$850	$260
3/8	10 - 13	.21 - .24	.215	895	260
1/2	12 - 15	.20 - .25	.210	825	350
1/2	15 - 22	.13 - .19	.160	955	415
3/4	15 - 19	.19 - .26	.220	1,030	420
3/4	20 - 30	.16 - .21	.180	1,000	525
1	26 - 41	.14 - .20	.180	1,500	622
1 1/2	36 - 47	.16 - .20	.175	1,360	790
2	40 - 65	.17 - .23	.190	3,520	925
Diesel or multiple electric motor drive					
2	45 - 80	0.16 - 0.24	0.200	(1)	1,020
3 - 5	109 -150	.15 - .20	.177	---	(2)

1 Diesel only. 2 Bucket included in pound price.

Excavator cranes

Gasoline or single electric motor drive

Clam size, cubic yards	Weight range, tons	Price per pound working weight		Extra per unit for Diesel power, average
		Range	Average	
3/8	7 - 9	$0.19 - $0.29	$0.240	$850
3/8	11 - 13	.21 - .24	.215	895
1/2	12 - 15	.19 - .24	.210	825
1/2	15 - 22	.13 - .19	.160	955
3/4	15 - 18	.19 - .22	.206	1,030
3/4	20 - 30	.15 - .21	.176	1,000
1	26 - 41	.13 - .20	.172	1,500
1 1/2	36 - 47	.16 - .19	.172	1,860
2	40 - 65	.17 - .23	.190	3,520
2 1	45 - 53	.22 - .24	.230	

1 Diesel only.

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Approximate cost of power-scraper equipment[1]

Size of bucket, cubic yards	Span, feet		Type of power drive			
	Customary	Maximum[2]	Belt	Electric	Gasoline	Oil or Diesel
1/3	200	300	$1,000	$1,400	$1,450	---
1/2	200	400	1,250	1,750	1,700	---
3/4	300	500	1,700	2,450	2,550	$3,400
1	300	500	1,350	2,800	2,950	4,250
1 1/2	400	500	2,450	3,550	4,000	5,200
2	400	600	3,400	4,700	5,400	6,100
2 1/2	300	800	5,300	8,000	8,750	9,800
3	300	800	5,700	9,100	9,850	10,600
4	400	800	7,250	11,000		

1 Cost includes bucket, hoist, cables, and fittings, f.o.b. factory.
2 Cost slightly increased for longer span.

Approximate cost of slackline-cableway equipment[1]

Size of bucket, cubic yards	Span, feet		Type of power drive			
	Customary	Maximum[2]	Belt	Electric	Gasoline	Oil or Diesel
1/3	300	400	$2,350	$2,900	$3,000	$3,600
1/2	300	400	2,750	3,350	3,450	4,000
3/4	400	500	3,750	4,750	4,850	6,150
1	500	600	4,250	5,450	5,900	6,950
1 1/2	500	700	6,100	7,750	8,450	10,250
2[3]	700	---	13,000	16,750	17,000	---
2 1/2[4]	800	---	16,500	22,250	---	---

1 Cost includes bucket, hoist, cables, and fittings, f.o.b. factory.
2 Cost slightly increased for longer span.
3 Cost includes 90-foot steel mast.
4 Cost includes 100-foot steel mast.

Hydraulic giants[1]

Size	Diameter of water inlet, inches	Giants, list price[2]	Deflectors, List price[2]
1	7	$165 - $180	$29
2	9	210 - 225	32
3	11	295 - 320	37
4	11	330 - 365	40
5	13	460 - 485	56
6	15	580 - 620	62
7	15	685 - 725	67
8	18	805 - 850	67
9	18	865 - 925	71

1 Gardner, E. D., and Johnson, C. H., Placer Mining in the Western United States. II. Hydraulicking, Treatment of Placer Concentrates, and Marketing of Gold: Inf. Circ. 6787, Bureau of Mines, 1934, p. 21.
2 Subject to discount.

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Spiral-riveted pipe[1]

Diameter, inches	Weight, pounds per foot	Bursting pressure, pounds per square inch	Cost per foot
8	7.1 - 8.8	935 - 1,170	$0.53 - $0.62
10	8.8 - 10.9	750 - 935	.66 - .77
12	10.5 - 13.0	625 - 1,080	.79 - 1.22
14	15.8 - 22.0	670 - 940	1.07 - 1.48
16	18.0 - 31.2	585 - 1,050	1.26 - 2.06
18	19.8 - 34.3	520 - 940	1.41 - 2.26
20	22.0 - 45.8	470 - 1,030	1.56 - 3.02
24	36.2 - 64.0	540 - 1,015	2.39 - 4.22
28	51.2 - 75.9	605 - 870	3.38 - 5.01
30	56.3 - 79.7	560 - 810	3.71 - 5.26
32	61.0 - 86.2	525 - 760	4.03 - 5.69
34	64.7 - 92.8	490 - 715	4.28 - 6.12
36	68.5 - 96.9	470 - 680	4.52 - 6.39

1 Gardner, E. D., and Johnson, C. H., Placer Mining in the Western United States. II. Hydraulicking, Treatment of Placer Concentrates, and Marketing of Gold: Inf. Circ. 6787, Bureau of Mines, 1934, p. 17.

Locomotives
(Cost in dollars per ton of weight)

Weight range, tons	Steam	Gasoline	Diesel	Electric	
				Trolley	Battery
5 - 50 4 - 20	260 - 550	350 - 600	435 - 700	550 - 900	600 - 1,200

Remote-control electric haulage

Cost ranges from $175 to $225 per ton-mile-hour capacity, exclusive of roadbed, rails, ties, etc.

Engine plane hoists

Up to 50 hp. costs average $70 per horsepower.
50 to 200 hp. costs average $55 per horsepower.

Industrial cars

Wood construction ranges from $70 to $90 per cubic yard.
Steel construction ranges from 10 to 20 percent higher.
For automatic couplers, air brake, etc., add $50 to $200 for each car.

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Motor trucks

Capacity, tons		Miles per gallon	Speed, miles per hour	Cost per unit	
Rated	Load			From	To
1	1 1/2	15	25	$800	$1,500
1 1/2	2 1/4	10	22	1,350	2,200
2	3	7	20	1,650	3,500
2 1/2	3 1/4	6 1/2	18	2,000	3,500
3	4 1/2	6	15	2,250	4,500
3 1/2	5 1/4	5 1/2	15	3,225	4,500
4	6	5	12	4,000	6,000
5	7 1/2	4	10	6,000	6,500

Dredge pumps

Size		Head, 25-100 feet	Speed r.p.m.	Power, hp. for each 10 feet of head at 12 feet per second velocity and 10 percent solids	Head, 100-150 feet	Speed, r.p.m.	Power, hp. for each 10 feet of head at 12 feet per second velocity and 10 percent solids
6-inch	Semimanganese	$740	450-900	5.05	$960	720-900	5.3
	Manganese	950			1,125		
8-inch	Semimanganese	1,125	360-722	9.35	1,355	600-720	9.2
	Manganese	1,360			1,735		
10-inch	Semimanganese	1,600	360-600	14.3	2,020	514-600	14.15
	Manganese	1,960			2,540		
12-inch	Semimanganese	2,200	300-514	20.5	2,520	450-514	19.7
	Manganese	2,690			3,180		
15-inch	Semimanganese	3,230	240-450	30.6	3,900	360-454	30.1
	Manganese	3,940			4,760		

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Aerial-tram installations

Rated hourly capacity, tons	Cost per mile exclusive of terminal bins [1]	
	Bicable	Monocable
5	$16,000 - $21,000	
10	14,000 - 22,000	$14,000 - $19,000
15	11,000 - 29,000	11,000 - 19,000
20	17,000 - 19,000	17,000 - 19,000
25	28,000 - 35,000	57,000 (short)
30	35,000 - 43,000	
50	37,000 - 48,000	
65	34,000 - 58,000	34,000 (long)
85	54,000 - 68,000	

1 Aerial-tram installation costs differ for each location. Those tabulated are actual examples illustrating possible range.

Wire rope

Improved plow-steel manufacturers' list less 25 to 30 percent.
Plow-steel manufacturers' list less 40 to 45 percent.
Cast-steel manufacturers' list less 25 to 30 percent.

ACKNOWLEDGMENTS

When this series of papers was planned it was not contemplated that the volume of the one on excavation should exceed the volume of those on prospecting and development. As the work progressed, however, it became evident that in order to treat the subject adequately the discussion should be expanded to include considerable detail. Much of the detail was beyond the scope of the personal experience of the author, and appeal was made to nationally known engineers and operators in the field for assistance in carefully reading the manuscript, criticising, correcting, and suggesting additions as needed. As a result the paper on excavation has been expanded to comprise 6 parts, each of which is as voluminous as the 2 preceding papers; the discussion of excavation and haulage equipment was made much more extensive and authoritative and the discussion as a whole made much more comprehensive. Space does not permit individual thanks and acknowledgment to the many who gave of their time and knowledge in the preparation of this paper, but the author does extend to them individually and collectively his sincere appreciation of their ready cooperation.

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